Opening the Black Boxes

Financial Algorithms and Multi-paradigmatic Research in Information Technology

Schinckus, Christophe; Gasparin, Marta; Green, William

Document Version
Accepted author manuscript

Published in:
Journal of Information Technology

DOI:
10.1108/JSIT-01-2020-0006

Publication date:
2022

Opening the Black Boxes: Financial Algorithms and Multi-paradigmatic Research in Information Technology

Abstract

Since the financial crisis in 2008, financial algorithms have been perceived as controversial and authorities have raised concerns on how they work after a new phenomenon, called flash, appeared in the financial markets. A flash crash is a very rapid and deep fall in security prices in a very short period of time due to an algorithmic misunderstanding of the market; thus, the interdisciplinary nature of algorithmization of financial markets poses a challenge also for information technology research. This article contributes to the recent debates on this topic by opening the black-box of the algoritmization of financial knowledge to understand how IT could address the challenges of the algorithmic configurations determined by the financial market. We analyze this black-boxed phenomenon in four steps. First, we present the flash crashes; then we conduct an epistemological analysis of the algorithmization through the identification three different regimes - epistemic, operational and authority - dealing with financial information. We explain that at the moment the regimes are mis-aligned, and it is necessary having a coherent organization to avoid a disconnection of financial information from economic reality. We suggest that IT can help managing the complexity of the algorithmization knowledge by diversifying algorithmization of financial markets through a multi-sensorial platform offering a better understanding of financial markets and therefore a better connection with economic reality. We conclude proposing sonification as a new possible way of capturing and understanding financial information and as new research area contributing to managing how financial innovations interact with information technology.

Keywords financial innovation, computerization of financial markets, algorithms, flash crash, sonification, epistemological regimes

Introduction

Since the financial crisis in 2008, financial innovations have been perceived as controversial. On the one hand, financial innovations are presented as an essential drivers of economic growth (Schöler, Skiera and Tellis, 2014); on the other, they are increasingly questioned in their capacity of creating values. In fact, the ripples of the 2008 crisis are still felt today in the economic and business reality, and they are frequently at the center of scholarly debates.

Even though financial innovations' discourses are organized around value creation (Souleles, 2017), their performance and outcomes are not always going hand-in-hand with value creation. In fact, in a number of unanticipated events, value has been destroyed rather than created. Flash crashes are telling examples of such situations. A flash crash is a very rapid and deep fall in security prices in a very short period of time, due to an algorithmic misunderstanding of the market in the automatized financial trading, and it can result in the loss of billions of dollars in few minutes or even few seconds (Schinckus 2018). The CNBC (Consumer News and Business Channel) and Business Insider recorded flash crashes on the 6th of May and on 23rd of April 2013 on the Dow Jones, on 15th of January 2015 on the Swiss Franc, on 6th of October 2016 on the British Pound (Lang, 2016), on the 22nd of June 2017 on the Etherum, on the 26th of June 2017 on the Gold Value, and on the 7th of July 2017 there was "another mysterious flash crash" (Javier and Barton 2017). Once the human errors are ruled out, finding the reasons that initiated and caused the flash crash is challenging, and it seems that in all the aforementioned cases computer systems were involved. In some cases, negative political speeches created negative reactions, for example for the Pound drop and in the 23rd of April's crash, or when the AP's tweeter account was hacked spreading fake news concerning the White House. The algorithms are programmed to analyze also factors external to the market place, thus political speeches that send negative signals to the markets can generate high levels of trading by selling as many assets as possible at a very high rate (Lang 2016). However, in other cases, a specific cause has not been found.

Flash crashes seem to spread rapidly to all kind of financial assets since they have occurred not only on the equity market, or on the bond market but, very recently, also on the currency market. Because flash crashes are generated by a loop-effect (i.e. a no-end selling trend) in trading algorithms, information technology plays a key role in these new phenomena. So, in this context, some questions emerge: why are flash crashes unanticipated, surprising and unmanageable events? What is the role of information technology in these flash crashes? What can be done to prevent them?

This is particularly concerning given the emergence of technological innovations in the financial sector (Condliffe, 2016), making difficult to clarify how it is possible to avoid unintended consequences that destroy value rather than create it. Finding an explanation is a challenging endeavor given the growing complexity of the financial industry (Shiller, 2012), and the interdependence between economies and societies (Shiller, 2008), and the unknown repercussion that financial innovations could have on these spheres (Muniesa, 2017). Information and technology research field could contribute addressing these compelling challenges.

Financial innovations have already generated several debates concerning the computerization of financial information that also echoes to the way information technology interacts with financial knowledge (MacKenzie, 2006). Algorithms are tools created through information technology frameworks whose conceptual content has been imported from financial economics (Muniesa, 2007). Specialists in IT and computer scientists designed the financial algorithms using specific theorems and pragmatic rules of investments coming from financial economics; however, in their practices, financial economists do not necessarily question the assumptions that have been made to develop the conceptual and technological tools they are using, considering them as black-boxed (Millo and Schinckus 2016; Schinckus 2016). Therefore, there is an opportunity for information systems researchers to open up the black box of financial innovations and question the axiomatic constructs that are at the basis of financial economy, by challenging the constituent theories. This is a very challenging task, since

> "the way scientific and technical work is made invisible by its own success. When a machine runs efficiently, when a matter of fact is settled, one need focus only on its inputs and outputs and not on its internal complexity. Thus, paradoxically, the more science and technology succeed, the more opaque and obscure they become (Latour 1999, pg. 304).

Blackboxing a theory is an operational necessity since it helps managing the complexity of techno-scientific theories transforming them into facts widely accepted, it also hinders the potential of solving problems that they might arise once the black box is opened and challenged (Latour, 1987). For example, having taken for granted the theories that are ruling the functioning of the trading algorithms, on the one hand leaves unpacked the economic black boxes when we dig into the other assumptions underlying technoscience constituting the algorithms, even though complexity also opens up opportunities for challenges to assumptions (Birch, 2017); on the other, new unintelligible unexpected events arouse and it had been possible to properly manage them, like the flash crashes (Schinckus 2016).

Because trading algorithms run on a computerized platform, the interdisciplinary nature of the concept of financialization poses a challenge for information technology research (Lagoarde-Segot and Currie, 2018); in our paper we aim to contribute to these recent debates by opening the black-box to further understand how IT could address the problematics of the algorithmic configurations happening in the financial market, and by explaining how IT could propose new approaches to mitigate the negative effects of emerging unexpected events. We will enquire the taken for granted dimension of financial knowledge by focusing on the way financial innovations interact with information technology and we propose sofinification as a new possible way of capturing and understanding financial information. Whilst this suggestion could be one of multiple possibilities, it is illustrative of a paradigmatic shift that is envisaged in a multi-paradigmatic view of IT and finance. We develop this reasoning in four steps.

Firstly, we present the emergence of flash crashes of the trading algorithms as counter-examples to what trading algorithms were theoretically supposed to offer. This investigation is intended to open the black-box of the computerization of the financial market and of what is theoretically expected from a financial innovation to define how financial innovations evolve from theoretical knowledge (*episteme*) to financial practices (*techne*).

Secondly, inspired by Lagoarde-Segot and Currie (2018) and by the numerous debates on the necessity to adopt a pluridisciplinary perspective in financial knowledge (Lagoarde-Segot 2015; Lagoarde-Segot 2017; Schinckus 2016; Schinckus 2018) , we unravel the epistemological dimensions of the computerization of trading algorithms. Building on the recent researches of sociology of finance, using this framework, we identify different regimes (epistemic, corresponding to the environment in which trading algorithms work, operational, corresponding to trading venues, and authority, corresponding to the authorities and actors working within the regulations sphere) dealing with financial information. These regimes are all constructed from the theory of efficient market hypothesis. However, its theoretical assumptions have been black-boxed and taken for granted, and each regime focuses only on a particular aspect of the theory, and therefore the resulting interpretations of the received information differ from one regime to the other.

We will discuss that creating unexpected speculations and potential predatory practices. Therefore, black-boxing knowledge has created different interpretations of the information circulating in the market, causing the flash crashes. We will demonstrate that the flash crashes are the outcome of a *lack of translation* between these three regimes. Translation is intended here in Serrian meaning, as a connection between otherwise disconnected things (Latour 1994). Not having the connections in place creates divergent interpretations on how technological tools understand financial information and implement financial knowledge, generating an hyper reality in which the financial markets are totally disconnected from the economic reality.

We propose a theoretical connection by integrating three different regimes to further understand the knowledge of the algorithmization of finance and this would allow IT scholars to develop appropriate tools to capture and analyze financial information to reduce the events that destroy value rather than create it.

We conclude by proposing some novel ways for IT research on how to contribute to a better understanding of the financial information, for example by implementing sonification principles.

The emergence of flash crash

On the 6th of May 2010, the Dow Jones Industrial Average felt about 9% within less than five minutes, which is a very short period of time in the financial market, and it was called "flash crash". This fall was due to "the combined selling pressure from the sell algorithm" (SEC, 2010). In fact, algorithms have been designed to react to news and events faster than humans, and in most of the situations, the human eyes cannot scan the amount of information that is processed by the algorithms. In the case of the flash crashes, people following the trade realized too slowly compared to the algorithms that the market has been frenetically selling and buying a very large volume of contracts. For example, in the 2010 crash, more than 27,000 contracts (49% of total trading volume, which meant that almost half of the market traded in 4 seconds) were traded within a four second period (very short period) according to the Securities and Exchange Commission (SEC) report (SEC, 2010). This was an "unreal situations" which caused a very rapid and deep fall of security prices in an extremely short period.

In the 2010 flash crash, a large part of the American economy (represented by the Dow Jones Industrial Average index) lost a significant percentage of its value in a few milliseconds. Whilst extreme variations and crashes are not uncommon in finance (Kindleberger, 1989), historically they have been the consequences and the results of human behaviors, and they had developed over a period of several days. In contrast, flash crashes appear in a few seconds because they do not result from human actions, but from computerized excitement of the market by algorithms, which create a loop effect in buying and selling trends. We have been witnessing that possibly because of the computerization of the financial markets, a strictly financial perspective has moved away from its function and has been disconnected from the economic and social reality (Schinckus 2017). Historically, financial markets were connected with and contributed to the economy by creating equilibrium between companies in need of capital and cash holders (Shiller, 2008). However, in the recent years, scholars have questioned whether the wealth created in the financial market has been really distributed outside the financial industry (Colander et al. 2009; Stiglitz 2010; Shiller 2012), since the financial sphere has appeared more and more disconnected from society, resulting in a predatory capitalism focused on short-term profit. In particular, when the real economy is stagnant, there is no justification for having a constantly high growth in the financial industry (Shiller, 2008), and while financial variables usually follow a power law behaviour, economic ones are rather characterized by an exponential distribution (Aoki and Yoshikawa, 2007). This means that there is an increasing difference between the statistical distributions characterizing the evolution of financial variables (e.g. stock returns, foreign exchange) and those describing economic fundamentals (e.g. growth of GDP) (Aoki and Yoshikawa, 2007). In the case of a flash crash, there is an unreal situation in which real money were lost within few second crash, even though the market went back to its "normal level" (Madrigal, 2010).

To conclude, in this economic and financial situation the flash clashes might have appeared because there is a significant decrease in the index that combined with a significant trade volume which meant that algorithms were operating simultaneously within a very short period of time, and created a paradoxical situation in which there was a market without referent (no economic justification) or trader (automated trade) (Schinckus 2008; Sajter and Coric 2009; Schinckus 2017).

In the next session we analyze how the paradoxical situation could have emerged as lack of translation between the different paradigms, in which the economic and financial actors operate.

Financial algorithms and epistemological disorder

Lagoarde-Segot and Currie (2018) called for a re-evaluation of algorithmization of financial sphere because of the increased complexity, impact on society and the interconnectedness of financial markets operating through algorithms at the global scale. There is also a political urgency to understand the algorithmization of the financial sphere because of the consequences for wider economy and society (Supervisors Group, 2015). Thus, in light of the eventalization of flash crash that happened in 6 May 2010, which has generated fear of technology and the fear of herding (Borch, 2016), we aim at understanding and discussing which is the context that favors the emergence of flash crashes, and at explaining why these unexpected events are linked to algorithmic and trading, since they have caused significant volatility and market disruption (SSG, 2015).

The analysis of the economic literature reveals that flash crashes and their negative effects on the value of the markets are not the effects of a lack of information, but an incapability of managing knowledge (Seyfert, 2016): since the complexity of the market is expanding, the complexity of knowledge and managing information is also expanding.

This difficulty of managing knowledge is not due to a lack of tools to extract data and information, but to a lack of appropriate processing of information to transform it into manageable knowledge.

Historically, the greatest financial markets, since the 1980s, have been automated and auctions on the trading floor conducted by brokers have been replaced by trading algorithms. Since the initial advent of trading algorithm, because of the increased efficiency in trading, each financial marketplace has been equipped with an electronic trading platform in which a large part of usual financial transactions can be automatically generated by "clever algorithms". Almost 70% of equities have been already traded algorithmically, and in the recent years this has expanded also for trading other less liquid categories of financial assets (The Economist, February 25, 2013). Firms performing algorithmic trading activities have benefited from a fragmented market structure in at by arbitraging prices between different trading venues, and traders now use trading strategies based on algorithms to arbitrage price differences (SSG, 2015). Even though traders can give orders to the algorithms to behave in a certain way, the behavior of the algorithms responds to market signals, and orders are executed by fully automated algorithms in fractions of a second (Borch, 2016). The markets are constituted by collective hybrids (Callon and Muniesa 2005 pg.1236), which are human and non-human actors who interact, collect data and perform decisions through calculative practices. (Mackenzie, 2014) has identified three main ecologies that are operating in the markets: trading algorithms, trading venues, and regulation. In analysing several papers (e.g. Coombs 2016; Lenglet and Mol 2016; Castelle et al. 2016) it emerged that, even though they are all based on the theory of efficient market hypothesis, these ecologies are using different analytical methods and are performing different roles and functions, since they are compliant with the rule and knowledge hierarchies within their institutional role. These rules and methods, therefore, are not only shaping the culture, practices and operationalization of the trading algorithms, but they are also shaping knowledge (Seyfert, 2016). However, so far, the knowledge within three ecologies have been analyzed separately. Because the IT platform is connecting all three ecologies, it is necessary to define their regimes and understand if and how they interact. A regime can be defined as a codified environment structuring financial information (Seyfert 2016), and this paper studies automatic algorithms through three different regimes that are reflecting the three ecologies: epistemic (corresponding to the trading algorithm ecology), operational (corresponding to trading venues ecology) and the authority (corresponding to the regulation ecology).

Because the regimes have an impact on how the reality is performed, in the next sub-sessions we will critically analyze them and how they relate to information and we will highlight that their lack of interaction can help us to better understand the occurrence of negative events, such as the flash crashes. This is a compelling task given their increasing importance in shaping social and economic life (Kitchin, 2017).

Epistemic Regime

The epistemic regime refers to the knowledge that has been used to construct and justify the implementation of trading algorithms. The epistemic regime refers to the term 'episteme' that involves a reflexive and formulated knowledge implying a possible distinction between action and deliberation (Millo and Schinckus, 2016). *Episteme* describes an abstract (conceptual) understanding of the world and it is usually associated with scientific knowledge in order to emphasize the certainty of its objects which do not change: scientific objects that are assumed to refer to immutable patterns.

In this regime, algorithms are artefacts that have been made (and used) in a specific cultural context that encompasses particular socio-economic values and assumptions. A better understanding of this theoretical contextual background is therefore important to clarify the way in which algorithms can be adapted and implemented, and how they can adjust to the changing society. In this section, we explain the socio-economic assumptions needed to justify the automatization of financial trading.

Trading algorithms did not pop up from nowhere. The idea of making financial market autonomous by using computers had been proposed by Black (1970) and gradually implemented in line with all theoretical principles of the financial mainstream. The epistemic regime is defined as a "way actors relate to financial markets, how they construct their market" (Slyfert, 2016, p.236). Automatic trading is a convenient way of organizing financial markets and improving their efficiency through technology. However, (Dupuy, 1992) explains that this computerization directly results from a certain ideological image of the market presented in Black's seminal article (Black, 1970). In the same vein, (Muniesa, 2000) explains that the automated conception of the market corresponds to the neo-classical idea of a perfect market in which financial prices quickly adjust to information in order to prevent arbitrage. This way of integrating the technological progress in finance results from a specific perception of the market based on the financial mainstream founded on the idea of the efficient market hypothesis (Fama 1965; Malkiel 1995).

In the case of financial mainstream, this episteme explicitly refers to a key notion in financial economics: the "perfectly competitive market" that designates clear characteristics of the market: better liquidity, better operational and informational efficiency, better transparency and lower transaction costs. This epistemic regime is based on a problem solving approach referring to a deductive way of creating knowledge by eliminating contradictions: after having defined the key characteristics (i.e. of perfectly competitive market) and listed the means (computers and algorithms) to materialize these characteristics, financial stakeholders developed automatic trading. This way of computerizing financial markets does not result from the potential reality (i.e. efficient markets do not exist) but it shapes the reality.

Empirical studies tend to show that automatic trading represents the best way of making real markets closer to our idealized conception of the efficient market (Fain and Roberts 1997; Claessens, Glaessner, and Klingebiel 2002; Jiang, Tang, and Law 2002); *The Economist* (February 27th, 2016). Consequently, the progressive computerization of financial markets is explicitly based on a particular representation of the market. (Mackenzie, 2006) shows that this "theorization" of financial practices existed before the computerization of markets through what he calls the "performativity" of models, which indicates that models largely used in practices actually shape the reality). The performativity was an important step towards a self-referent finance because this dimension was subsequently enhanced by computers, which gave the opportunity to create an automated imaginary projection (implementation) of a theory that appears to be a reification of theory (this claim has been studied in more detail in (McGoun 1997; Macintosh 2003; Schinckus 2008; Baldwin 2011; Macintosh, 2003). We will discuss in further details this aspect in the fourth section of this article.

In accordance with the epistemic regime, computers and algorithms follow a better rationality, to identify the arbitrage opportunity and to make the "right decisions" quicker than human beings. The theoretical argument behind this computerization refers to the necessity of exploiting all arbitrage opportunities in order to bring equilibrium to financial markets (Wang *et al.*, 2009), which is not always created. In fact, the emergence of flash crashes is an example illustrating the unexpected consequences of this epistemic regime since a loop-effect leading to a selling trend generated a non-perfect competitive (and irrational) situation. The occurrence of flash crashes is partly due to the way through which trading algorithms have been operationalized. The next sub-section investigates further this point.

Regime of operationalization

The ecology of trading venues belongs to the regime of operationalization since it results from the way actors implement and reify the epistemic regime through specific technologies. The analysis of this regime is based on the works of Seyfert (2016) and (Borch, 2016) who studied the 'eventalization' (i.e. how make visible and become an event) of financial algorithms through their practical effects. The operational regime is the one in which information technology specialists are mainly involved since it refers tools, techniques and practices engaged in the implementation of algorithms. The road to a theoretical perfect computerized financial market was not straightforward and two important steps has been implemented: 1) the *automatization of transactions* in the 1980s and 1990s that denoted a radical innovation[1] whose implementation was successful (because it met all expectations in terms of market efficiency) and; 2) in the 2000s, its extension to the *automatization of profit seeking processes* (i.e. financial trading algorithms).

This progressive evolution allows to increase the speed at which the algorithms are computing in relation to their ability to analyze and to take a position in the market. The automatization of profit seeking process (algorithmization) is founded on the assumption algorithms are logical and they can take advantage of all potential arbitrage situations and benefited from technology that reduced delay and latency to the markets (SSG, 2015). The theoretical foundation led to the idea of implementing a technological environment in which computerized agents can take positions as a fast as possible to

[1] See Green and Cluley (2014) for an introduction to radical innovation.

take advantage of potential arbitrage. This particular maximization of profit seeking shapes the algorithms in a such way that they react very quickly to specific stimuli (variations in financial prices) coming from the market. In the case of a flash crash occurs, a specific situation happens: although algorithms use diverse parametrizations, they all react in the same way (but with different intensity) to variations of financial prices,

{Figure 1: Loop effect when a flash crash occurs}

As indicated in figure 1, a flash crash occurs when all algorithms start to interpret in the same way a particular stimulus (significant reduction of financial prices) coming from the market, however, so-doing, they actually re-inforce the stimulus that led them to sell financial instruments. This situation creates a loop-effect. Although algorithms operate with different configurations and parametrizations looking for a maximization of profit, a flash crash is an un-expected situation in which the sum of individual rational computerized decisions become collectively irrational (disconnected from socio-economic justification).

The implementation of algorithms was based on an orthodox financial model assuming rationality of agents (computers). In particular, the operationalization regime has been implemented as a mere technological extension of the epistemic regime based on the assumption that this computerization will create financial practices in line with what financial knowledge (*episteme)* expected. In terms of knowledge, the algorithmization of financial information refers to what we call '*techne*' that concerns the world of practices in the everyday contingencies. *Techne* is an applied (non-formulated) knowledge (traders do their jobs everyday, without being asked why they are doing their tasks). The translation between the epistemic regime to the operational one has been under-investigated in the recent computerization of financial sphere, according to Schinckus (2017). In this context, stakeholders did not consider that the implementation of algorithms could eventually change the functioning of markets. However, this automatization of profit seeking processes generated "the Flash Crash illustrates an unwanted domino effect, in which algorithms cause other algorithms to respond to market moves in specific ways" (Lange, Lenglet, and Seyfert 2016, pg. 151). Interestingly, the unexpected flash crashes are in contradiction with the initial purpose of the innovation; they are actually operational counter-examples of the epistemic regime that assumed that a computerized efficient market would ensure a rational and stable environment for financial trades. This so-called computerized efficient market generates a paradoxical "inhuman irrationality" (non-human irrationality).

Because of the impossibility of canceling all transactions (Muniesa, 2014), stakeholders realized that the implementation of algorithms have a real effect over the organization of the financial market, and that tools implemented by information technology specialists have a real effect that alter the socio-cultural context (Borch, 2016). Thus, the unexpected consequences of the operationalization of a knowledge that justifies this situation calls for further studies on this *episteme*. In fact, the occurrence of flash crashes also suggests that there is not a proper translation between the epistemic regime justifying the existence of algorithms and their operational implementation, and would be important to decipher where the misunderstanding is happening. This mis-translation is even enhanced and spread at the level of financial authority as explained in the following section.

Regime of authority

The authority regime concerns the political regulation and actions taken by markets authorities. The regulation of financial algorithms is probably one of the most problematic theme in our contemporary society due to the difficulty to define what is an algorithm (Lenglet, 2011). We derived the existence of such regime from the works of Coombs (2016) and Castelle et al. (2016) who discussed the major challenges of the current financial regulation regarding algorithms. The role of the authority regime is to provide a stable and coherent environment defining the rules of the game for financial trade. Such context actually refers to what Millo and Schinckus (2016) called *epitaktike* which refers to "a commanding knowledge" (Parry and Reynolds, 2007, p.7). While the concept of episteme describes an abstract (theoretical) understanding of the world, *epitaktike* rather "gives commands whose effects are practical" (Parry, 2007, p.7). An illustration of this sort of knowledge is architecture, which considered a theoretical and abstract field since it does not concretely construct a building, which is what carpentry does; however, architecture has direct and practical implications by shaping the work done by carpenters. Of course, *episteme* and *epitaktike* are interconnected since the former provides conceptual tools to the latter to define its structuring principles: architecture (*epitaktike*), for instance, uses a lot of mathematical notions (*episteme*) to define its commanding knowledge to the carpenter (*techne*). In relation to algorithmization, the regime of authority acknowledges (*epitaktike*) the necessity to improve the computerization of financial sphere. Financial knowledge (*episteme*) therefore helps to design algorithms whose practical effects imply new practices (*techne*) that stay under the legal control of financial authority. However, concerning the occurrence of flash crashes, financial authorities acknowledge that the situation is still unclear. Due to the complexity to define what is an algorithm, it is difficult to integrate this concept into a legal framework (Lange, Lenglet and Seyfert, 2016b). Furthermore, the diverse uses of algorithms create a situation in which the regulator cannot find a practical definition as Coombs (2016) explained it,

> "Regulators were shocked that nobody in the firms knows sometimes how algorithms work – what is the decision path? I don't know. I push this button. Full stop" (Coombs, 2016, pg 286).

Authorities themselves emphasized "it is extremely difficult to identify whether the overacting algorithm is a unique whole or has by means of its sub-parts" (FIA, 2014, p.48). In this context, regulator acknowledged the 'un-knowledgeability' of the automated market indicating a misalignment between the epistemic, the operational and the authorization regimes of such market. In this 'interpretative chaos', the knowledge offered by the epistemic regime is the only source of intelligibility and it therefore played the role of commanding knowledge (*epitaktike*) for the authority regime. Precisely, financial authorities usually define the regime of authority by adjusting their rules in line with the existing epistemic regime. For instance, in accordance with the financial mainstream, the SEC (Security Exchange Commission) responded to the flash crash by centralizing the control of circuit breakers, in order to secure the market and keep the market quiet[2]. Circuit breakers have the ability to "switch off" the market and to stop all transactions when the market appears to be excited, or with too many variations. In agreement with the efficient market hypothesis defining what should be a computerized market, the financial authority considered that a market (or the transactions on a single stock) must be halted if one can observe a significant variation of the price in a short period of time:

> "the exchanges are required to issue five minutes halts in a security if the price of that security moves at least 10% in either direction from its prices in the preceding five minutes period" (SEC, 2010, at.5).

[2] According to the financial mainstream, a perfect efficient market is a market with few large variations (Fama, 1970).

Serritella (2010, p.442) explained how this rule appears to be inappropriate for two reasons: 1) a variation of 10% is sometimes justified on the financial markets and 2) this rule cannot avoid the effect of a flash crash because algorithms can do thousands of transactions in five minutes.

Financial authorities aim to preserve the efficiency and integrity of the market when unexpected events, such as flash crashes, appear (SEC, 2010 note 5, at 11) because a "flash crash exposed dangerous factures in our market's foundations" (Serritella, 2010, p.434) and can push the stock prices into a downward spiral engendering market chaos (Goldstein 2010). However, switching off the market might solve the problem in the short term but this solution does not help to understand the origin of flash crash nor to prevent the occurrence of new one. Switching off the market focuses on the necessity to keep the financial variations as smooth as possible in line with the conceptual frame (epistemic regime) that justified the computerization of financial trade. Such solution actually indicates a misundertanding of this regime. The regime of authority is supposed to rule potential problems by providing a commanding knowledge, not merely repeating the theoretical framework that generated the problem. Furthermore, this solution does not cover the un-thought consequence of implementation of this theoretical framework.

To conclude, in this section we presented the different regimes through which algorithms are reified. The emergence of unexpected flash crashes can actually be seen as a mistranslation between these three modes of existence of trading algorithms as detailed in the following sub-section.

Necessity to have a coherence of regimes

Financial sphere and its role in the society is very complicated (Shiller, 2012), since the diversity of stakeholders combined with the increasing progress in technology makes the situation inextricably complex (Muniesa, 2007). Indeed, unexpected events linked to algorithmic and high frequency trading have caused significant volatility and market disruption, leading to heightened debate around the risks these activities pose to the functioning of global markets (SSG, 2015, Seyfert, 2016*).*

To ensure a smooth computerization of financial markets, this 'regimization' of financial algorithms must be coherent. Stakeholders want a stable (i.e not too risky) financial environment in which interrelations between the three regimes will not generate unexpected economic problems\ costs. In this ideal situation, one would expect a kind of linearity in the reification of financial algorithms as illustrated in the following figure 2,

{ Figure 2: Algorithmization of financial knowledge }

Our analysis led to the construction of Figure 2. Figure 2 analyzes the epistemic regime as theoretically and scientifically justification of the existence of financial algorithms and provided that theoretic knowledge is implemented through an operational regime restructuring the trading operations. This process is then validated and supported by an authority regime. Figure 2 shows how the three ecologies and their relative epistemic regimes would function if there would be a proper translation of knowledge between the different ecologies. In this idealized situation, the three regimes would deal with the same interpretation of financial information and the algorithmization would lead to a coherent presentation and production of information.

However, reality is much more complex: the implementation of financial algorithms involves academics, analysts, traders, computer specialists, lawyers etc.; all these actors belong to different specific regime and have their own way of thinking and consequently implementing the algorithms. Jovanovic and Schinckus (2017), for instance, show how practitioners, traders, jurists and economists use the same concept 'efficient market' while they refer to different disciplinary context. This difference between actors partly explains the existing mis-translation between the three regimes. The mis-translation is compelling because it can also alter the translation in terms of knowledge between the three regimes making the information uncertain and ill-defined. Precisely, if the three regimes operate in a non-coherent and unified way, then practices (effect of algorithms) will have no link at all with their theoretical (*episteme*) and legal (*epitaktike*) justification. In such challenging situation, the implementation of algorithms can then lead to the occurrence of un-expected phenomena in which operational regime is disconnected from epistemic, legal and societal aspects as schematized in the diagram hereafter, figure 3

{ Figure 3: Algorithmization of financial knowledge with the occurrence of flash crashes}

On this schema, the three regimes are not unified paving the way to a self-referent operation regime in which algorithms act and re-act to each other in a loop reasoning disconnected from society. In such context, algorithms created what Schinckus (2017) called a hyper-reality in which one can observe a trade without traders (except computers) nor economic justification since trade only results from a computerized loop-effect without any link with the economic reality. In this perspective (illustrated in the figure 3), algorithms go out of the financial sphere creating a challenging situation for the financial authority. In fact, the financial authorities have a lack of understanding of what is happening in the market, therefore, it cannot provide a reliable and guiding knowledge. In such context, the role authority regime is ill-defined since it appears as simple legal decision to reaffirm the epistemic regime when its implementation is not in line with the theoretical expectations. Although we acknowledge that something had to be done, such reaction reduced the commanding knowledge (*Epitaktike*), theoretical knowledge (*Episteme*) and create therefore mistranslations between regimes. This situation leads actors to 'play false' in order to save the currently accepted principles of the epistemic regime against practical inadequacies. However, when serious mis-translations between *episteme* (knowledge) and its *techne* (practices) occurs, it is necessary to return to a creative perception\implementation of the gap between them, which might cause flash crash phenomenon. Flash crashes are crucial effect challenging financial knowledge and its reification. Flash crashes create a situation in which financial markets might be totally disconnected from its socio-economic and legal reality. In such context, it is timely to analyze how IT could help finance to improve the information and reduce the risk of disconnection with other regimes and society. This kind of crashes calls for a new creative play, a novel approach to the three regimes analyzed in this section.

The next section will investigate further some exploratory paths that might help finance and information technology to have a better understanding of the emergence of flash crashes.

Information technology and financial complexity

Digitalization of trading generated a lot of debates in IT research (see the double issue devoted to this topic in this journal, edited by Lagoarde-Segot and Currie (2018). As evoked earlier, the computerization of financial markets refers to a multi-layered reality involving several disciplines. Of course, this phenomenon directly concerns information technology, and as Lagoarde-Segot and Currie (2018, p.1) emphasized it,

> "Information technology researchers will need to acknowledge that the selection of relevant research questions as well as the methods used to answer them and the interpretation or research results are influenced by tacit paradigmatic assumptions".

In the previous section, we evoked the major assumption supported by the epistemic regime (i.e. assumption of perfect and efficient market). When flash crashes occurred, some commentators mentioned that technology used in high frequency trading created a situation of high uncertainty and unfairness (Madrigal, 2010). Technology is a vehicle for conveying information, and the way financial information is computerized implicitly refers to a paradigmatic knowledge (i.e. epistemic regime). The digitalization of financial information inexpertly created flash crashes. The increase of unexpected consequences called for a paradigmatic diversification of knowledge not only in financial economics, but also in information technology as illustrated by the special issue recently edited by Lagoarde-Segot and Currie (2018) in this journal.

Thus, we question how IT could contribute to the adoption of a multi-paradigmatic view of financial trading digitalization. In this perspective, we do not consider information technology simply as a tool-maker (merely implementing an existing financial knowledge) but rather as a tool-creator research area, offering new potential source of knowledge[3]. We adopt here the position promoted by Bunker (2001) who wrote,

> "Tools are not only technical in nature and function but must also fulfil a social role by reinforcing relationships within cultures and between cultures. IT tools can change relationships and their social and business context" (Bunker, 2001, p.191).

IT can provide tools that could be used by humans and computers to create new financial practices. We illustrate this claim through the example of sonification. There have already been some attempts in diversifying the financial knowledge. For example, Knox et al. 2010[4] have already discussed how information technology can influence financial knowledge by increasing the visual dimension of financial markets. Similarly, Bettner, Frandsen and Mcgoun (2010) suggest to use algorithms for the transformation of accounting data into music, as it is possible to hear different patterns in it than we see when it is transformed into a graph. Thus, we suggest IT can extend the epistemic range of access to also to financial reality by using another component of information technology to create and manage information: sounds. This approach requires the so called sonification. Sonification refers to the transformation of data into audible sound (Sterne and Akiyama, 2012), and it can be defined as

> "the exploitation of sound as one of the principal channels conveying information, meaning, and aesthetic/emotional qualities in interactive context" (Pinch and Bijsterveld 2012, p.8).

There are different fields of research concerning sonification, which includes the field of acoustic ecology, sound design, urban studies, cultural geography, media and communication studies, cultural studies, the history and anthropology of senses, the history of sociology of music and literary studies (Pinch and Bijsterveld, 2012). Sounds

---

3 Actually, the occurrence of flash crashes is also a source of new knowledge but these phenomena were unexpected and even un-thought.

4 Finance is a field in which visual elements play a key role since data are usually created visually before being statistically validated.

are widely used in science as sensory data used to produce knowledge and solve problems (Smith 2012,Krebs 2012, Ferguson, Martens, and Cabrera 2011). Whilst Pinch and Bijsterveld (2012) suggest that people might need to learn new skills in order to transform auditory data in knowledge, Thomas Hermann, Hunt, and Neuhoff (2011) argue that displaying information using sound has been demonstrated to be a better way to convey information. Sonification has been implemented in medical science to enhance diagnosis of dementia (Roginska *et al.*, 2014) and cardiac pathologies (Kather *et al.*, 2017). Evidences show that this method has increased the accuracy of diagnosis from 85% to 92% for dementia and from 78% to 90% for cardiac pathologies. Previously, sonification has been used for monitoring tasks in mechanic and engineering industries to identify acoustic patterns that might indicate warning signs and potential problems with machineries (Kramer,1994). Also, in aeronautics for instance, a sound-based analysis is used to identify critical situation in a very short period of time. Sounds based intelligent alarm systems are implemented to save critical seconds that, in turn, will help to save the aircraft by immediately attracting the pilot's attention on potential important problems (Brungart and Simpson, 2008). In line with this argument, instead of relying on our visual memory and visual analysis, we propose that the organization of the financial market would benefit from sonification by transforming data analysis into an acoustic signal for the purpose of facilitating communication the interpretation of the signals coming from the market (as in (Hermann, Hunt and Neuhoff, 2011). For example, one financial variable (for instance, volatility) would be mapped while the shift of another would be associated with its pitch. Several timbres of sound could then be added to create a data-rich soundscape. The idea is to offer a complementary way of perceiving reality with an auditory display in order to exploit the superior ability of the human auditory system component compared to the visual one in recognizing patterns and making it more efficient in displaying complex situations that change in times (Hugill, 2012). Since more sources of knowledge can participate in knowledge dynamics and creation more successfully (Hermann, Hunt and Neuhoff, 2011). Therefore, sonification of financial information can contribute to the development of multi-modal\sensorial platform in which the interactions between computers and human beings would be improved to avoid catastrophic episodes such as the flash crashes.

In fact, listening is not only a way of acquiring information, but it can also be used for diagnostic, monitoring, synthetic and exploratory activities (Pinch and Bijsterveld, 2012). Stakeholders (including authorities) can disrupt their epistemological dimension through explorative listening to discover new phenomena or to extend their way of perceiving and analyzing their environment (Pinch and Bijsterveld, 2012).

For example, the Securities and Exchange Commission (SEC) authorities, could use sonification to listen to markets in order to identify potential auditory harbingers of a crash. Such new way of analyzing financial data would offer a potential room for detecting (flash) crashes and therefore adjusting the way trading algorithms are implemented (Neuhoff, 2011). Sonification would extend the epistemic domain of financial knowledge. This extension could uncover new, currently unseen, effects of disruptive innovation. Sonification will create a multi-sensorial dataset in order to have a better understanding of financial information. In this context, the operational regime (through the use of practices) can be supported by new communication methods to implement in a pluri-modal interactions with the financial markets. So doing, sonification paves the way to a new way of implementing knowledge of financial markets and at the same time it also offers a new way of capturing financial information contributing therefore to an improvement of the epistemic regime. In the same vein, sonification can translate the relationships of an event into information that exploits the auditory capabilities to make them intelligible. Thus, the progressive computerization of financial reality would benefit from the sonification of financial knowledge to extend and enhance the way of perceiving potential consequences of such evolution.

In a context of sonification, we could have a multi-modal platform increasing the interactions between technological and human actors as suggested by the schema hereafter, as indicated in figure 4

{Figure 4: Algorithmization of financial knowledge by promoting sonification}

To some extent, sonification can become another dimension of the algorithmization of financial markets focusing on the auditory outcomes of algorithms. In this perspective, sonification covers the epistemic and operational regimes since it also affects practices. At the same time, algorithms alter the knowledge we have from financial markets justifying their link with the epistemic regime.

To conclude, sonification combined with classical algorithmization of financial markets offer a multi-sensorial (auditory and visual) understanding of financial sphere. This aspect can improve the way of capturing, understanding, and modelling financial data contributing to the epistemic knowledge. Furthermore, the translation of financial information into sounds propose new methods of investigation (noise analysis) that could have beneficial effects for stakeholders in the financial sphere. As in the case of the aeronautic, in which sounds are used to alert pilots, such way of dealing with critical moments could actually be useful for the implementation of an efficient tool for authority regime. Indeed, in addition to its usual roles evoked in the previous section, the authority regime might have more information\indicators to capture harbingers of potential crashes. Such mixed between epistemic regime (*episteme*) and operational one (*techne*) is usually presented as a necessary condition to developed what philosophers of science call a *phronesis.* (Aristotle (1999) introduced this concept in his Book VI for describing a practical knowledge implemented in accordance with a "practical wisdom" or a "particular ethics". In a sense, *phronesis* can be seen as a practical knowledge (*techne*) guided by a deep understanding of the situation (*episteme*) and ethical strength. For financial authority, *phronesis* refers to the necessity of avoiding the development of financial markets that would be in total disconnection of economic reality (Shiller, 2012 explained the destructive aspect of such evolution). By diversifying algorithmization of financial markets, information technology can contribute to *phronesis* by increasing all ways of understanding, analyzing and capturing financial data and also by extending practices in this field.

Conclusion

This article aims to contribute to the recent debates on algorithmization of financial knowledge by discussing the black-boxed aspects of financial algorithms to further understand how IT could address the challenges of the algorithmic configurations determined by the financial market. With this purpose, we provided an epistemological analysis of the algorithmization through the identification different regimes (epistemic, operational and authority) and dealing with financial information. We explained the current problems with the organization of these regimes and how the mis-translation between these regimes might generate a hyper-reality in which financial markets are totally disconnected from economic reality. We discussed the necessity to have a coherent organization of these regimes to avoid a complete disconnection of financial information with economic reality. We then discuss how IT could diversify algorithmization of financial markets through a multi-sensorial alternative (sonification) offering a better understanding of financial markets. By diversifying algorithmization of financial markets, information technology can contribute to financial knowledge by increasing all ways of capturing, analyzing and understanding financial data but also by extending practices in this field. Further researches should aim at designing a sofinication system to be tested in the market.

Reference

Aoki, M. and Yoshikawa, H. (2007) *Reconstructing macroeconomics: a perspective from statistical physics and combinatorial stochastic processes*. Cambridge: Cambridge University Press.

Aristotle (1999) *Nicomachean Ethics, Book 1, chapter 6*. Available at: http://www.perseus.tufts.edu/hopper/text?doc=Perseus:text:1999.01.0054:book=1:chapter=6 (Accessed: 24 March 2018).

Baldwin Jon (2011) *The Financial Crash and Hyper-Real Economy | Thought Catalog*. Available at: https://thoughtcatalog.com/jon-baldwin/2011/08/the-financial-crash-and-hyper-real-economy/ (Accessed: 23 March 2018).

Bettner, M. S., Frandsen, A. C. and McGoun, E. G. (2010) 'Listening to accounting', *Critical Perspectives on Accounting*, 21(4), pp. 294–302. doi: 10.1016/j.cpa.2009.11.005.

Birch, K. (2017) 'Techno-economic Assumptions', *Science as Culture*, 2 October, pp. 433–444. doi: 10.1080/09505431.2017.1377389.

Black, F. (1970) 'Banking and Interest Rates in a World without Money', *Journal of Bank Research*. Hoboken, NJ, USA: John Wiley & Sons, Inc., pp. 1–22. doi: 10.1002/9781119203070.ch1.

Borch, C. (2016) 'High-frequency trading, algorithmic finance and the Flash Crash: reflections on eventalization', *Economy and Society*, 45(3–4), pp. 350–378. doi: 10.1080/03085147.2016.1263034.

Brungart, D. S. and Simpson, B. . (2008) 'Design, validation, and in-flight evaluation of an auditory attitude indicator based on pilot-selected music', in *Proceedings of the 14th International Conference on Auditory Display, pp. 24e27.*, pp. 24–27. doi: 10.1080/16486897.2007.9636935.

Bunker, D. (2001) 'A Philosophy of Information Technology and Systems (IT & S) as Tools:

Tool Development Context, Associated Skills and the Global Technology Transfer (GTT) Process', *Information Systems Frontiers*, 3(2), pp. 185–197. doi: 10.1023/A:1011443406476.

Callon, M. and Muniesa, F. (2005) 'Peripheral Vision Economic Markets as Calculative Collective Devices', *Organization studies*. Sage Publications, 26(8), pp. 1229–1250.

Castelle, M. *et al.* (2016) 'Where do electronic markets come from? Regulation and the transformation of financial exchanges'. doi: 10.1080/03085147.2016.1213985.

Claessens, S., Glaessner, T. C. and Klingebiel, D. (2002) *E-finance in emerging markets: is leapfrogging possible?* Wiley Online Library.

Colander, D. *et al.* (2009) 'The financial crisis and the systemic failure of the economics profession', *Critical Review*. Taylor & Francis, 21(2–3), pp. 249–267.

Condliffe, J. (2016) 'Algorithms Probably Caused a Flash Crash of the British Pound', *MIT technology Review*.

Coombs, N. (2016) 'What is an algorithm? Financial regulation in the era of high-frequency trading'. doi: 10.1080/03085147.2016.1213977.

Dupuy, J.-P. (1992) *Liberalisme et Justice Sociale*. Paris: Hachette-littératures.

Fain, D. and Roberts, M. Lou (1997) 'Technology vs. consumer behavior: The battle for the financial services customer', *Journal of Interactive Marketing*. Elsevier, 11(1), pp. 44–54.

FIA. (2014). FIA Association reply form for the ESMA MiFID II/MiFIR discussion paper

Ferguson, S., Martens, W. and Cabrera, D. (2011) 'Statistical sonification for exploratory data analysis', *The Sonification Handbook*. Edited by T. Hermann, A. Hunt, and J. G. Neuhoff. Berlin: LOGOS, pp. 175–196.

Goldstein M (2010) *UPDATE 3-US stock plunge raises alarm on algo trading*, *May 7, 20108:31 AM*. Available at: https://www.reuters.com/article/market-selloff/update-3-us-stock-plunge-raises-alarm-on-algo-trading-idUSN0624451020100507 (Accessed: 24 March

2018).

Green, W. and Cluley, R. (2014) ‘The field of radical innovation: Making sense of organizational cultures and radical innovation’, *Industrial Marketing Management*. Elsevier, 43(8), pp. 1343–1350.

Hermann, T., Hunt, A. and Neuhoff, J. G. (2011) *The sonification handbook*. Logos Verlag Berlin.

Hugill, A. (2012) *The digital musician*. New York: Routledge.

Javier Luzi-Ann and Barton Susanne (2017) *Another Bullion Flash Crash Is Testing Traders - Bloomberg*, *7 July* . Available at: https://www.bloomberg.com/news/articles/2017-07-07/another-bullion-flash-crash-is-testing-the-nerve-of-traders (Accessed: 23 March 2018).

Jiang, G., Tang, N. and Law, E. (2002) ‘Electronic trading in Hong Kong and its impact on market functioning’, *BIS Papers chapters*. Bank for International Settlements, 12, pp. 124–137. Available at: https://ideas.repec.org/h/bis/bisbpc/12-07.html (Accessed: 23 March 2018).

Jovanovic, F. and Schinckus, C. (2017) *Econophysics and Financial Economics*. Oxford University Press. doi: 10.1093/acprof:oso/9780190205034.001.0001.

Kather, J. N. *et al.* (2017) ‘Polyphonic sonification of electrocardiography signals for diagnosis of cardiac pathologies’, *Scientific Reports*. Nature Publishing Group, 7, p. 44549. doi: 10.1038/srep44549.

Kindleberger, C. P. (1989) ‘Long waves in economics and politics’, *Economics & Politics*. Wiley Online Library, 1(2), pp. 201–206.

Kitchin, R. (2017) ‘Thinking critically about and researching algorithms’, *Information, Communication & Society*, 20(1), pp. 14–29. doi: 10.1080/1369118X.2016.1154087.

Knox, K. (2010) ‘Dancing the Dow : Accounting and Financial Information Embodied Dancing the Dow : Accounting and Financial Information Embodied Abstract’, *http://apira2010.econ.usyd.edu.au/conference_proceedings/APIRA-2010-316-Frandsen-Accounting-and-financial-information-embodied.pdf*. Available at: http://apira2010.econ.usyd.edu.au/conference_proceedings/APIRA-2010-316-Frandsen-Accounting-and-financial-information-embodied.pdf (Accessed: 24 March 2018).

Kramer, G., Santa Fe Institute (Santa Fe, N. M. . and International Conference on Auditory Display (1st : 1992 : Santa Fe, N. M. . (1994) *Auditory display : sonification, audification, and auditory interfaces*. Addison-Wesley.

Krebs, S. (2012) 'Sobbing, Whining, Rumbling--Listening to Automobiles as Social Practice', *The Oxford handbook of sound studies*. Edited by T. Pinch and K. Bijsterveld. New York: Oxford University Press, pp. 79–101.

Lagoarde-Segot, T. (2015) 'Diversifying financial research: Final remarks', *International Review of Financial Analysis*. Elsevier, 41, pp. 28–30.

Lagoarde-Segot, T. (2017) 'Financialization: Towards a new research agenda', *International Review of Financial Analysis*. North-Holland, 51, pp. 113–123. doi: 10.1016/J.IRFA.2016.03.007.

Lagoarde-Segot, T. and Currie, W. L. (2018) 'Financialization and information technology: A multi-paradigmatic view of IT and finance – Part II', *Journal of Information Technology*, 33(33), pp. 1–8. doi: 10.1057/s41265-017-0045-7.

Lang (2016) *Money talks: Flash Crash Bang Wallop by The Economist*. Available at: https://soundcloud.com/theeconomist/money-talks-flash-crash-bang-wallop (Accessed: 23 March 2018).

Lange, A.-C., Lenglet, M. and Seyfert, R. (2016a) 'Cultures of high-frequency trading: mapping the landscape of algorithmic developments in contemporary financial markets'. doi: 10.1080/03085147.2016.1213986.

Lange, A.-C., Lenglet, M. and Seyfert, R. (2016b) 'Cultures of high-frequency trading:

mapping the landscape of algorithmic developments in contemporary financial markets'. doi: 10.1080/03085147.2016.1213986.

Latour, B. (1987) *Science in action: How to follow scientists and engineers through society*. Cambridge, Massachussetts: Harvard University Press.

Latour, B. (1994) 'On technical mediation- philosophy, sociology, genealogy', *Common Knowledge*, Fall V3(2), pp. 29–64.

Latour, B. (1999) *Pandora's hope: essays on the reality of science studies*. Cambridge, USA: Harvard University Press.

Lenglet, M. (2011) 'Conflicting Codes and Codings', *Theory, Culture & Society*. SAGE PublicationsSage UK: London, England, 28(6), pp. 44–66. doi: 10.1177/0263276411417444.

Lenglet, M. and Mol, J. (2016) 'Squaring the speed of light? Regulating market access in algorithmic finance'. doi: 10.1080/03085147.2016.1213080.

Macintosh, N. B. (2003) 'From rationality to hyperreality: paradigm poker', *International Review of Financial Analysis*. North-Holland, 12(4), pp. 453–465. doi: 10.1016/S1057-5219(03)00035-8.

Mackenzie, D. (2006) 'Is Economics Performative? Option Theory and the Construction of Derivatives Markets', *Journal of the History of Economic Thought*, 28(1), p. 29. doi: 10.1080/10427710500509722.

Mackenzie, D. (2014) 'A Sociology of Algorithms: High-Frequency Trading and the Shaping of Markets', *Preprint*, (June), pp. 1–67. Available at: http://www.sps.ed.ac.uk/__data/assets/pdf_file/0004/156298/Algorithms25.pdf (Accessed: 12 March 2018).

MacKenzie, D. A. (2006) *An engine, not a camera : how financial models shape markets*. MIT Press.

Madrigal, A. (2010) ‘Market data firm spots the tracks of bizarre robot traders’, *The Atlantic (August 4, 2010)*.

Malkiel, B. G. (1995) ‘Returns from investing in equity mutual funds 1971 to 1991’, *The Journal of finance*. Wiley Online Library, 50(2), pp. 549–572.

McGoun, E. G. (1997) ‘Hyperreal Finance’, *Critical Perspectives on Accounting*. Elsevier, 8(1–2), pp. 97–122.

Millo, Y. and Schinckus, C. (2016) ‘A nuanced perspective on techne and episteme in finance’, *International review of financial analysis*, 46, pp. 124–130.

Muniesa, F. (2000) ‘Un robot walrasien. Cotation électronique et justesse de la découverte des prix’, *Politix*. Persée - Portail des revues scientifiques en SHS, 13(52), pp. 121–154. doi: 10.3406/polix.2000.1122.

Muniesa, F. (2007) ‘Market technologies and the pragmatics of prices’, *Economy and society*. Taylor & Francis, 36(3), pp. 377–395.

Muniesa, F. (2014) *The Provoked Economy: Economic Reality and the Performative Turn*. Abingdon: Routledge.

Muniesa, F. (2017) ‘On the Political Vernaculars of Value Creation’, *Science as Culture*, 26(4), pp. 445–454. doi: 10.1080/09505431.2017.1354847.

Neuhoff, J. G. (2011) ‘Perception, Cognition and Action in Auditory Displays’, *The Sonification Handbook*. Edited by T. Hermann, A. Hunt, and J. G. Neuhoff. Berlin: Logos Publishing House, pp. 63–85.

Parry, M. A. J. and Reynolds, M. P. (2007) ‘Improving resource use efficiency’, *Annals of Applied Biology*. Wiley/Blackwell (10.1111), 151(2), pp. 133–135. doi: 10.1111/j.1744-7348.2007.00182.x.

Pinch, T. and Bijsterveld, K. (2012) *The Oxford handbook of sound studies*. New York:

Oxford University Press.

Roginska, A. *et al.* (2014) 'SONIFICATION METHOD TO ENHANCE THE DIAGNOSIS OF DEMENTIA', in *The 20th International Conference on Auditory Display (ICAD-2014)*. New York. Available at: https://smartech.gatech.edu/bitstream/handle/1853/52066/Roginska et al. - SONIFICATION METHOD TO ENHANCE THE DIAGNOS.pdf (Accessed: 24 March 2018).

Sajter Domagoy and Coric Tomislav (2009) *(I)rationality of Investors on Croatian Stock Market â□□ Explaining the Impact of... | Request PDF*. Zagreb. Available at: https://www.researchgate.net/publication/23992844_Irationality_of_Investors_on_Croatian_Stock_Market_a_Explaining_the_Impact_of_American_Indices_on_Croatian_Stock_Market (Accessed: 23 March 2018).

Schinckus, C. (2008) 'The financial simulacrum: The consequences of the symbolization and the computerization of the financial market', *The Journal of Socio-Economics*. Elsevier, 37(3), pp. 1076–1089.

Schinckus, C. (2016) 'Critical Perspectives on Accounting', *Pataphysics of finance: An essay of visual epistemology*.

Schinckus, C. (2016) 'Pataphysics of finance: An essay of visual epistemology', *Critical Perspectives on Accounting*. Elsevier.

Schinckus, C. (2018) 'An essay on financial information in the era of computerization', *Journal of Information Technology*. Palgrave Macmillan UK, 33(1), pp. 9–18. doi: 10.1057/s41265-016-0027-1.

Schinckus Professor of Finance, C. (2016) 'Pataphysics of finance: An essay of visual epistemology'. doi: 10.1016/j.cpa.2016.08.003.

Schöler, L., Skiera, B. and Tellis, G. J. (2014) 'Stock market returns to financial innovations before and during the financial crisis in the United States and Europe', *Journal of Product*

Innovation Management. Wiley Online Library, 31(5), pp. 973–986.

Serritella, D. M. (2010) ‘HIGH SPEED TRADING BEGETS HIGH SPEED REGULATION: SEC RESPONSE TO FLASH CRASH, RASH’, *Journal of Law, Technology and Policy*, pp. 433–444. Available at: http://illinoisjltp.com/journal/wp-content/uploads/2013/10/Serritella.pdf (Accessed: 24 March 2018).

Seyfert, R. (2016) ‘Bugs, predations or manipulations? Incompatible epistemic regimes of high-frequency trading’, *Economy and Society*, 45(2), pp. 251–277. doi: 10.1080/03085147.2016.1213978.

Shiller, R. J. (2008) *The subprime solution : how today’s global financial crisis happened and what to do about it*. Princeton, N. J.: Princeton University Press. Available at: http://www.loc.gov/catdir/toc/ecip0814/2008013734.html.

Shiller, R. J. (2012) *Finance and the Good Society*. Oxford, UK: Princeton University Press.

Smith, M. M. (2012) ‘The Garden in the Machine: Listening to Early American Industrialization’, *The Oxford handbook of sound studies*. Edited by T. Pinch and K. Bijsterveld. New York: Oxford University Press, pp. 39–57.

Souleles, D. (2017) ‘Something new: value and change in finance’, *Journal of Cultural Economy*. Taylor & Francis, pp. 1–12.

Sterne, J. and Akiyama, M. (2012) ‘The recording that never wanted to be heard and other stories of sonification’, *The Oxford Handbook of Sound Studies*. Edited by T. Pinch and K. Bijsterveld. New York: Oxford University Press, pp. 545–561.

Stiglitz, J. E. (2010) *Freefall: America, free markets, and the sinking of the world economy*. WW Norton & Company.

Supervisors Group, S. (2015) ‘Algorithmic Trading Briefing Note’. Available at: https://www.newyorkfed.org/medialibrary/media/newsevents/news/banking/2015/SSG-algorithmic-trading-2015.pdf (Accessed: 12 March 2018).

Wang, J. X. *et al.* (2009) 'Design and implementation of an agent-based collaborative product design system', *Computers in industry*. Elsevier, 60(7), pp. 520–535.

U.S. Securities and Exchange Commission and the Commodity Futures Trading Commission (September 30, 2010). "Findings Regarding the Market Events of May 6, 2010". Archived from the original on 10 October 2010. Retrieved 2 October 2017.